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PROJECT ADMINISTRATION DATA SHEET

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Project Director: ~~James J. McShirley~~ School/Lab EML

Sponsor: Naval Research Laboratory

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Title: 85.5 GHz Dual Polarization Radiometer

ADMINISTRATIVE DATA OCA Contact Frank H. Huff X4820

1) Sponsor Technical Contact:

*see notice of award OR pg 3

2) Sponsor Admin/Contractual Matters:

Thomas A. Bryant
ONR RR
Ga. Inst. of Tech.
206 O'Keefe
Atlanta, Ga 30332
(404) 881-4213

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(or) Company/Industrial Proprietary: ______

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See Attached Gov't Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Gov't, but none proposed. Note that radiometer is a deliverable & classified as Materials & Supplies

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Project No. A-3434 — ~~School~~/Lab EML

Includes Subproject No.(s)

Project Director(s) J. A. Gagliano — GTRI / ~~GIT~~

Sponsor Naval Research Laboratory

Title "85.5 GHz Dual Polarization Radiometer"

Effective Completion Date: 2/25/84 (Performance) 2/25/84 * (Reports)

*however expenses incurred after 2/25/84 to complete the final report are allowable. (memo dtd. 3/19/84)

Grant/Contract Closeout Actions Remaining:

- [ ] None
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A-3434

85.5 GHz DUAL POLARIZATION RADIOMETER

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY

A Unit of the University System of Georgia
Atlanta, Georgia 30332

GTRI
GEORGIA TECH RESEARCH INSTITUTE

May 1985

OPERATION/MAINTENANCE MANUAL

Prepared for

NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375

Contract No. N00014-83-C-2009

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A 85.5 GHz radiometer was designed, constructed, and delivered to NRL as part of the Special Sensor Microwave Imager (SSM/I) simulator to be used onboard NRL's RP3-A aircraft. The radiometer has dual polarization, self-calibration, temperature control operation and a remote control unit.

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Operation/Maintenance Manual

85.5 GHz Dual Polarization Radiometer

R. E. Forsythe
D. M. Guillory
A. T. Howard
D. C. Rady

May 1985

Contract No. N00014-83-C-2009

Georgia Tech Project No. A-3434

For
Naval Research Laboratory
Washington, D. C. 20375

Georgia Institute of Technology
Georgia Tech Research Institute
Atlanta, Georgia 30332

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SUMMARY

The instrument described in thi 85.5 GHz, dual polarization Dicke radio receives and detects both vertica linearly polarized energy. The rad temperature controlled base plate that added stability. It is to be used as c which simulate the SSM/I system on boa is designed for stare only operation i converted to a total power mode for us radiometer uses an all solid state whose specifications are extremely close to those of the SSM/I 85.5 GHz radiometer. The radiometer also has its own internal calibration system that operates in an automatic or manual mode. A remote control unit is also provided.

Preface

This report was prepared by the Electromagnetics Laboratory of the Georgia Tech Research Institute under NRL Contract N00014-83-C-2009. The contract technical monitor was Dr. James P. Hollinger. The contract period was from November 1982 to July 1985. This document describes the performance, operation and maintenance aspects of the radiometer.

The authors of this report are Mr. R. E. Forsythe, Mr. D. M. Guillory, Ms. A. T. Howard and Mr. D. C. Rady. The views and conclusions of this report are those of the authors and should not be interpreted as necessarily representing the official policies of the Naval Research Laboratory or the U. S. Government.

1.0 Introduction

The purpose of this program was to develop an aircraft version of the 85.5 GHz radiometer that is to be used as part of the SSM/I simulator on the NRL RP3-A aircraft. The Special Sensor Microwave Imager (SSM/I) will eventually be flown on the Defense Meteorological Satellite Program (DMSP) and the Georgia Tech developed radiometer will simulate as closely as possible the corresponding satellite radiometer.

Figure 1 is a block diagram of the radiometer system consisting of the sensor (RFI sub-enclosure), the internal calibration and Dicke reference loads with chopper, and the remote control unit. The radiometer front end (mixer, pre-amplifier, and local oscillator chain) was procured as a sub-assembly with specifications similar to the satellite sensor front end. The radiometer was designed to allow for operation in either the total power, or the Dicke mode. However, some modifications need to be made to operate in the total power mode as will be discussed later. Table 1 is a summary of the system performance specifications for the 85.5 GHz radiometer. Photographs of the system are provided in Figures 2 through 6.

The system primarily consists of the antenna, two calibration loads, the Dicke reference load, mechanical (fan blade) chopper, the orthomode transducer, dual channel downconverter/LO/preamp assembly, IF amplifiers, IF filters, square law detectors, video amplifier, and phase sensitive detectors. The system uses a rotating fan-blade chopper to quasi-optically switch the antenna between the external scene or the calibration loads and the Dicke load which is held to a constant temperature by heat sinking the load material to the temperature controlled baseplate. A rotating bar with 45^{o} angled reflectors, mounted in front of the chopper, switches alternately between the hot and cold calibration loads during each calibration cycle by steering the antenna beam.

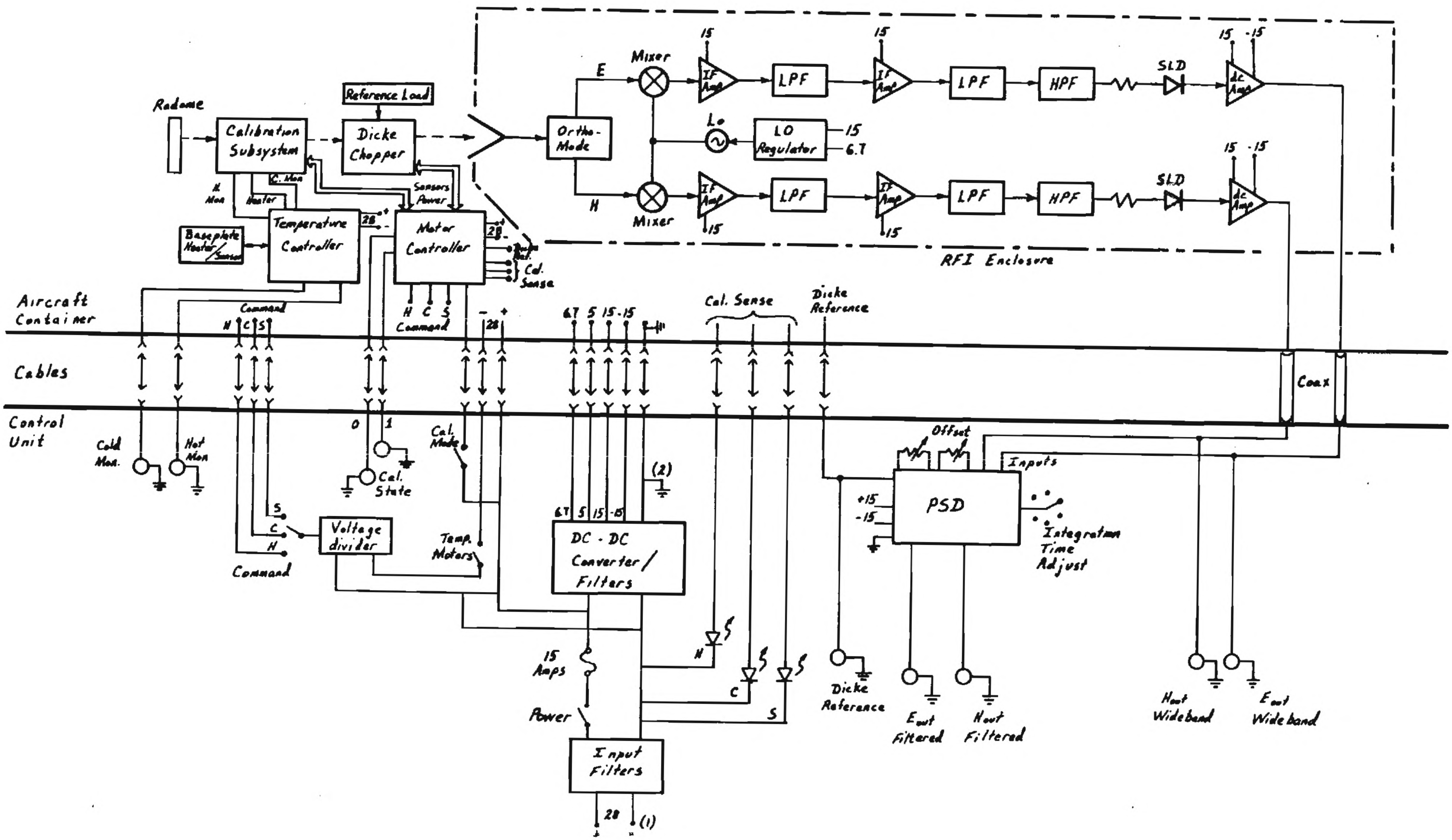


Figure 1: 85.5 GHz System Block Diagram

TABLE I. RADIOMETER PERFORMANCE SUMMARY

Polarization	Simultaneous Horizontal and Vertical
Cross Polarization	<-25 dB
Calibration	Absolute
Calibration Accuracy	$\pm$1K, 100K$<T_{ANT}<$400K*
Hot Reference Temperature	340K Nominal
Cold Reference Temperature	AMBIENT, Depends on Outside Air
Dicke Reference Temperature	300K Nominal, Controlled by Baseplate Temp.
RF Center Frequency	85.5 GHz
IF Passband	100 to 1000 MHz
Integration Time (τ)	50 msec (adjustable 1 msec - 1 sec)
Antenna 3 dB Beamwidth	7 degrees
Output Voltage for T_a=0 to 400K	0 to +2 Vdc Nominal
Output Offset Adjustment Range	$\pm$10 Vdc
Input Power	26 to 30 Vdc
Chopping Frequency	150 Hz
ΔT_{min} (at τ = 1 sec.)	0.13K E, 0.10K H
System Noise Figure	8 dB E, 7 dB H
Calibration Period	Automatic - once every 7 sec. Manual-switch controlled
Stability (10 min.)	2K drift max. after warm up with 0.05 sec τ.
Power Supply Noise Rejection	50dB (0.1 to 5 kHz) Min.

* Depends on number of samples taken, stability, integration time, sensitivity, and load temperature.

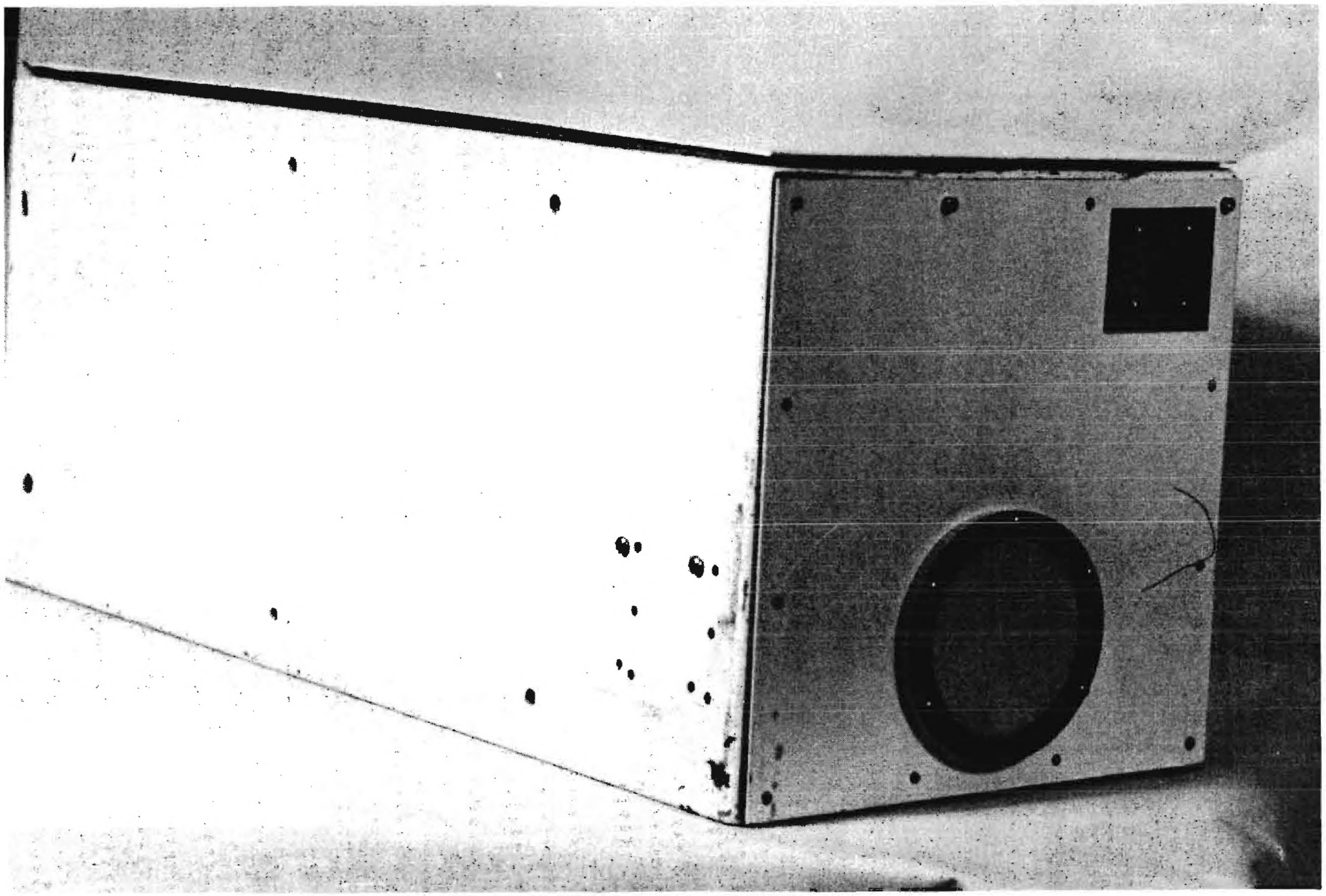


Figure 2. Photograph of 85.5 GHz Radiometer

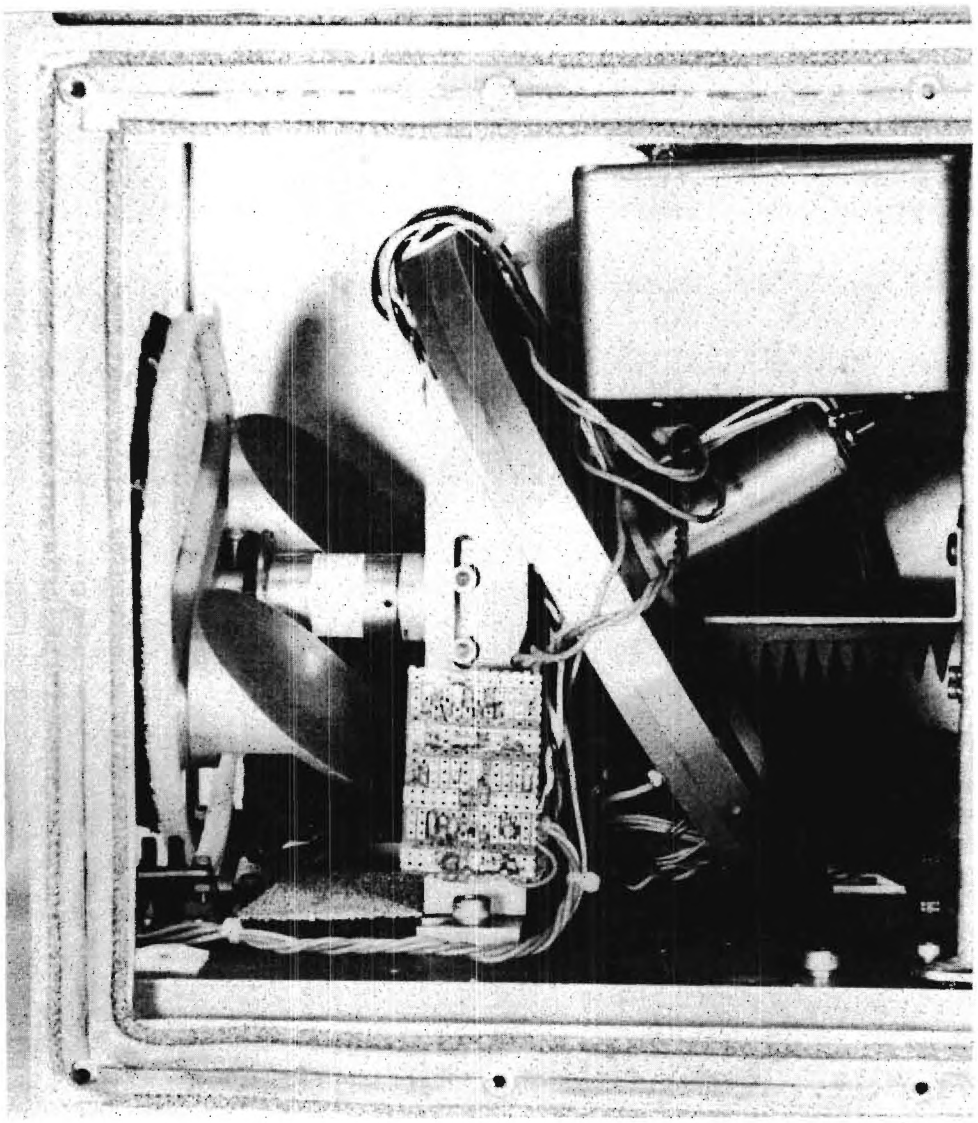


Figure 3. Photograph of Side View of 85.5 GHz Radiometer Calibration/Dicke Chopper Mechanisms

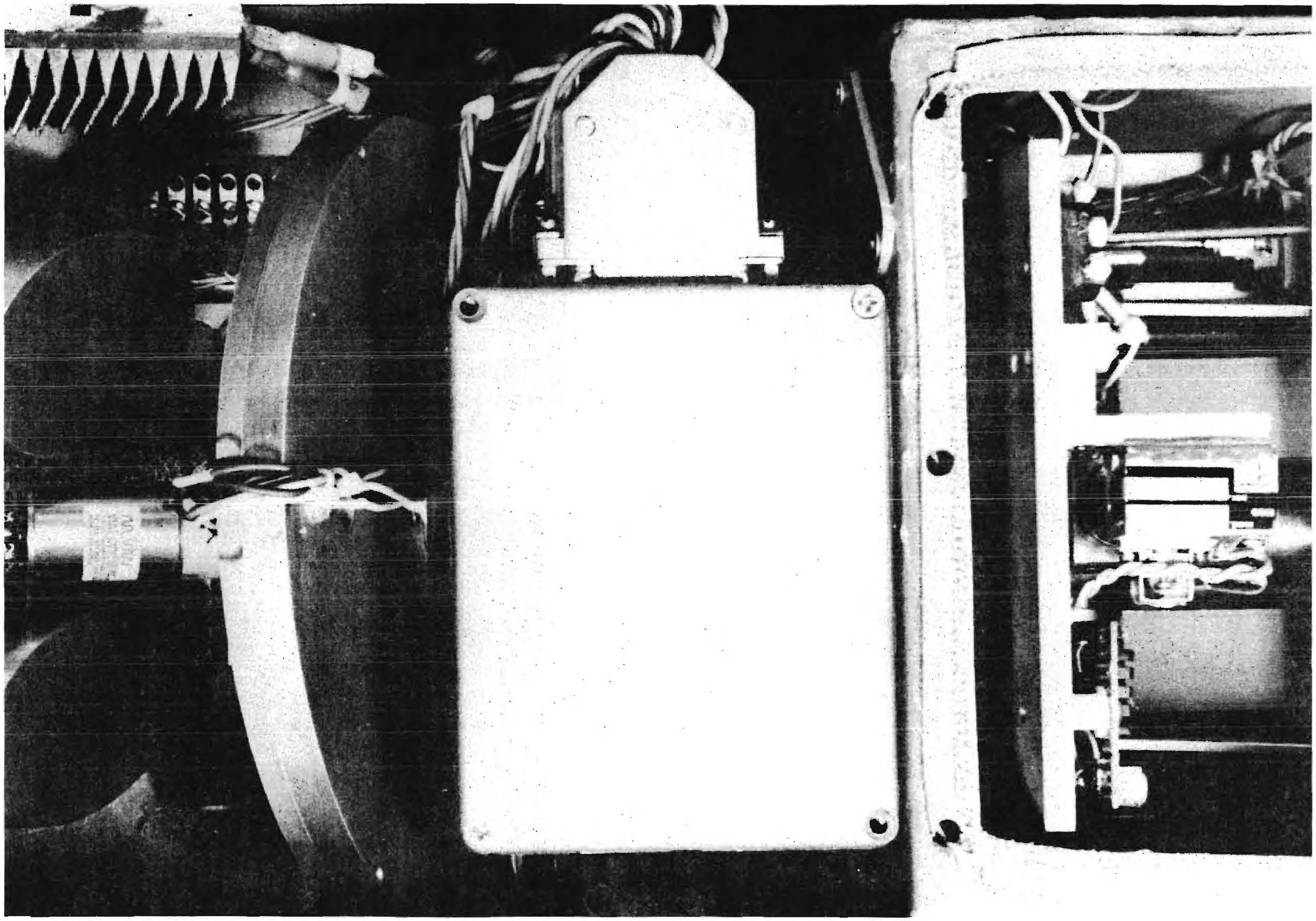


Figure 4. Top View of Calibration Reflectors, Loads, and Temperature/Motor Control Box.

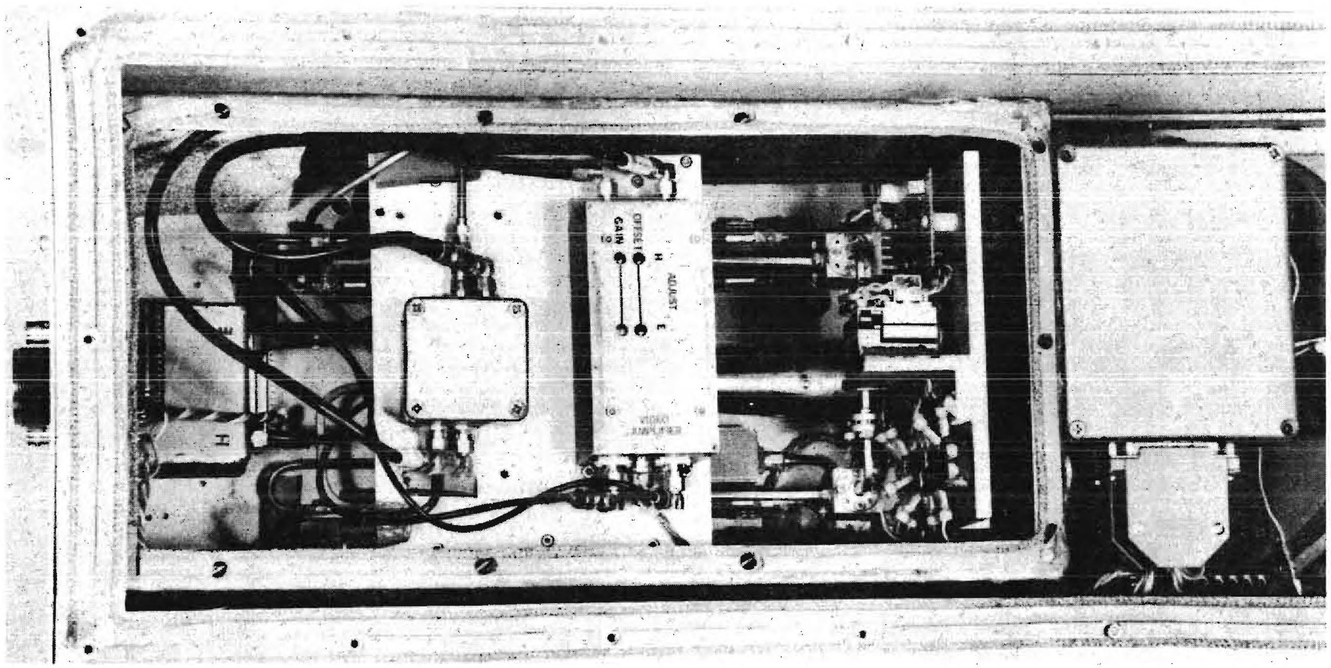
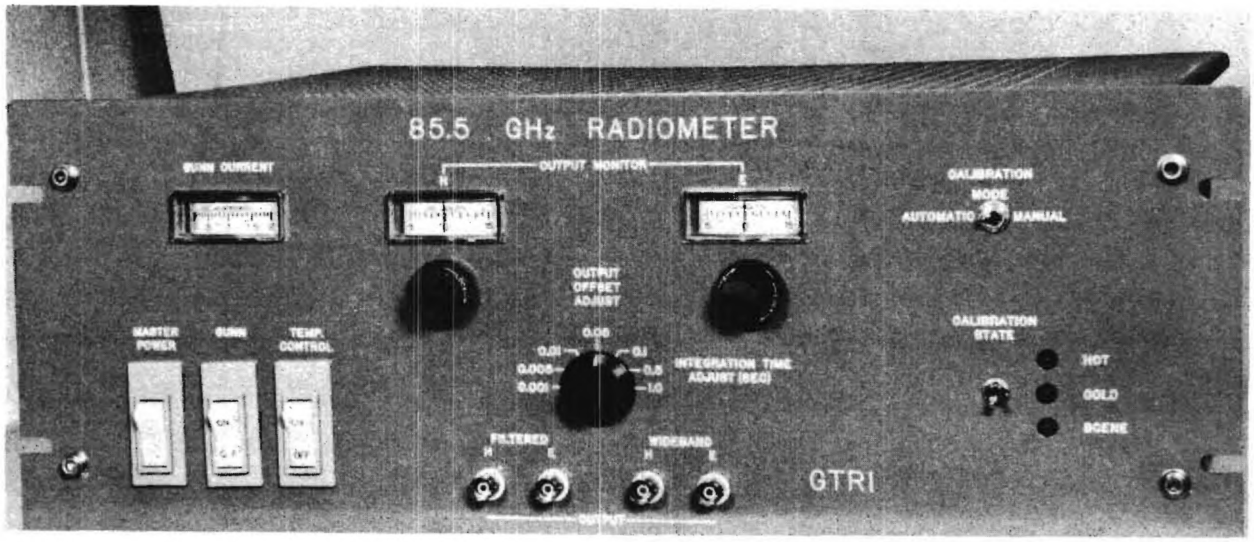


Figure 5. Top View of 85.5 GHz RF/IF Subsystem



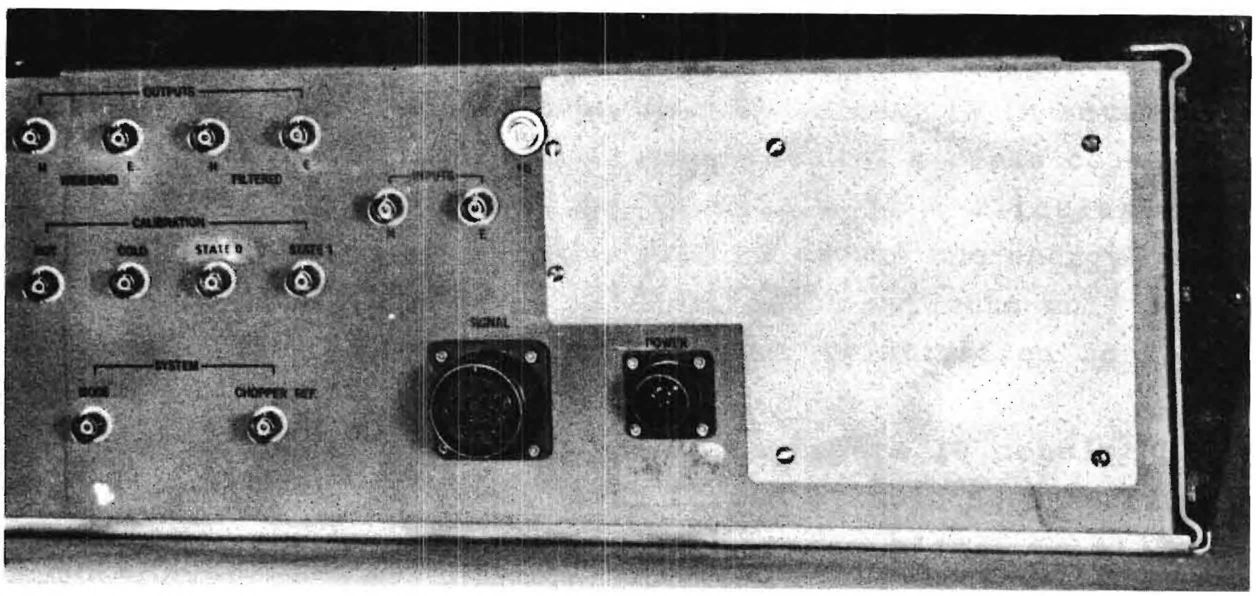


Figure 6. Front and Back Views of Control Unit

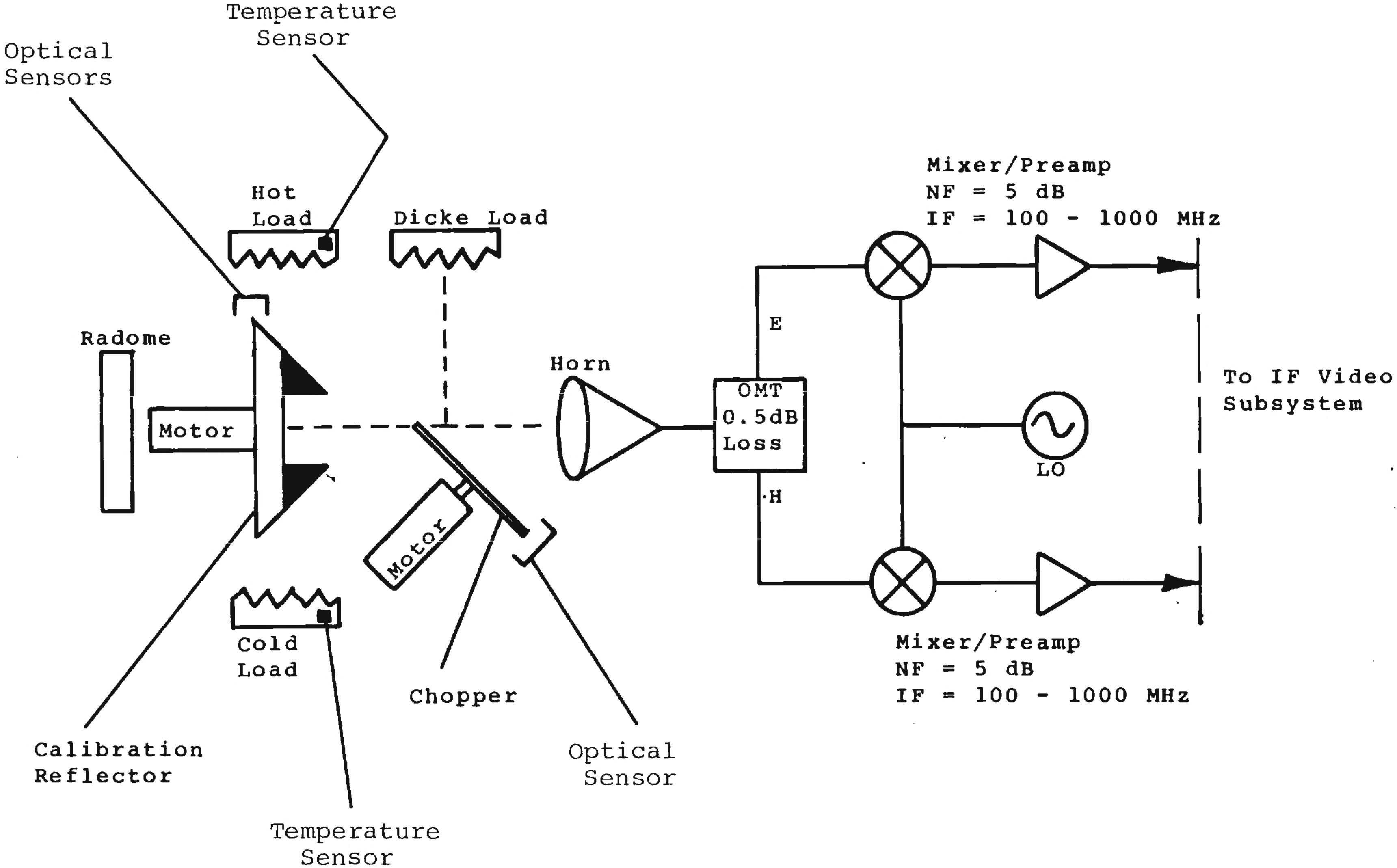


Figure 7: RF Subsystem Block Diagram

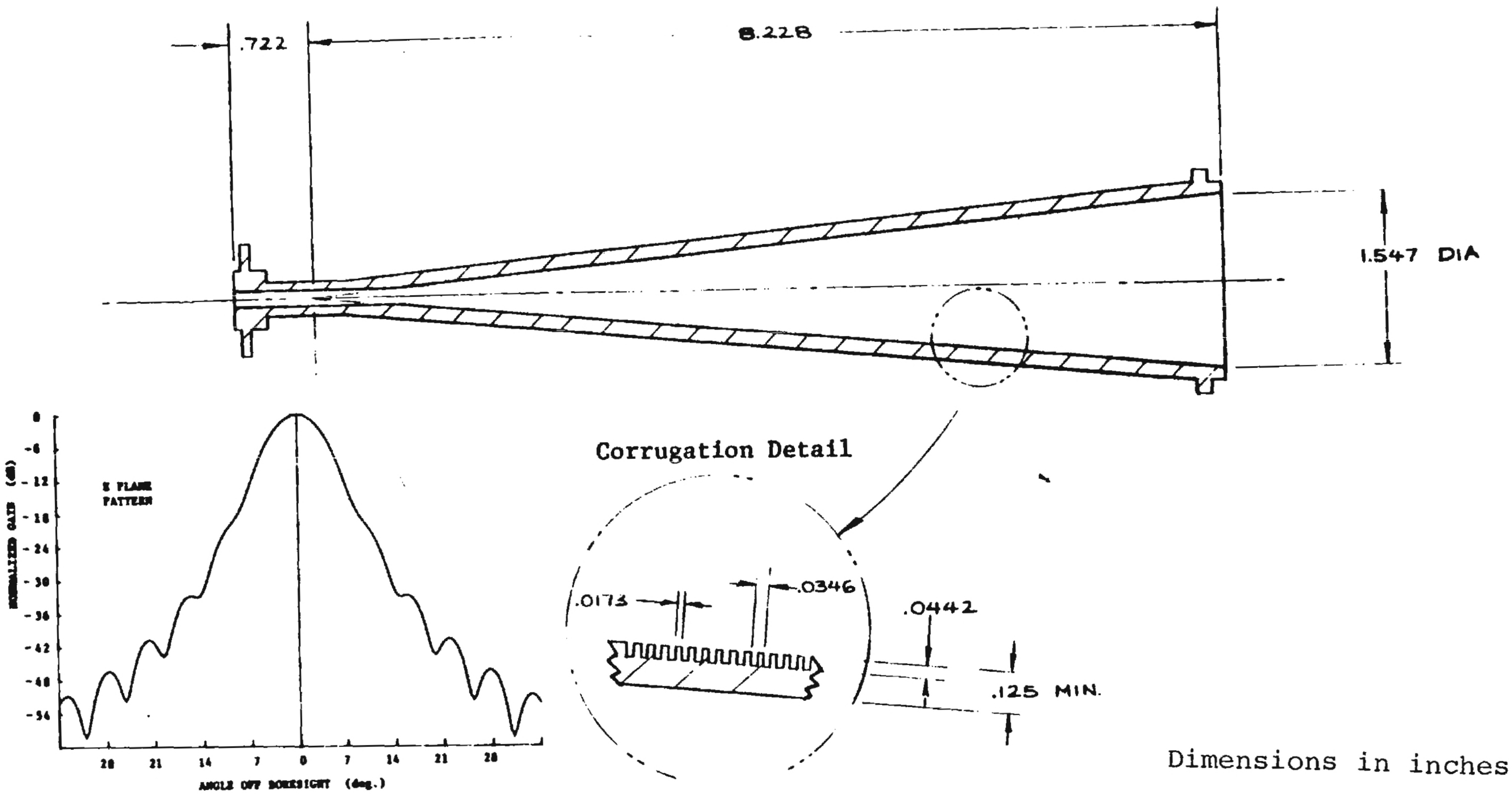
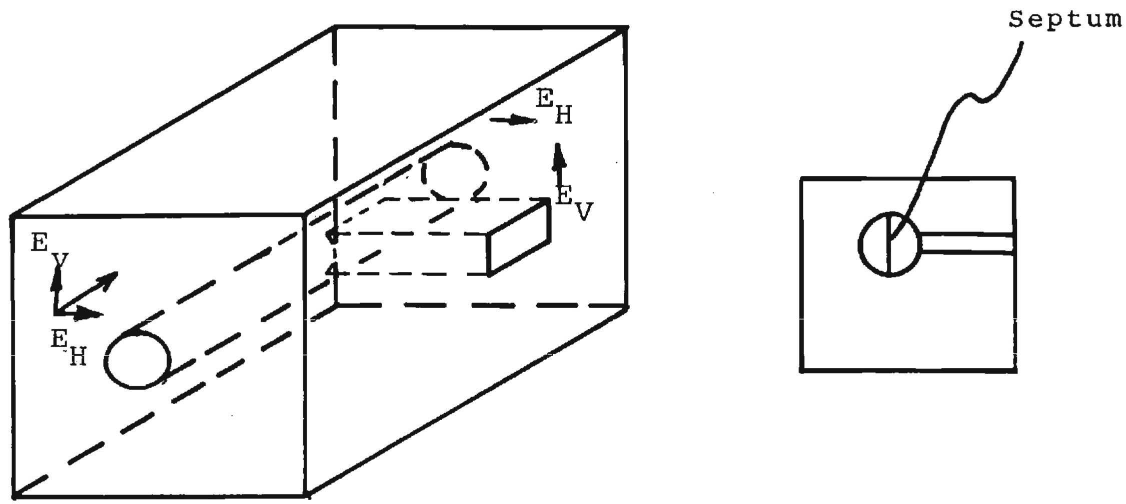


Figure 8. Corrugated Conical Horn Diagram



Horizontal $\longrightarrow E_H \longrightarrow$ H

Vertical $\longrightarrow E_V \longrightarrow$ V

Figure 9: Orthomode Transducer

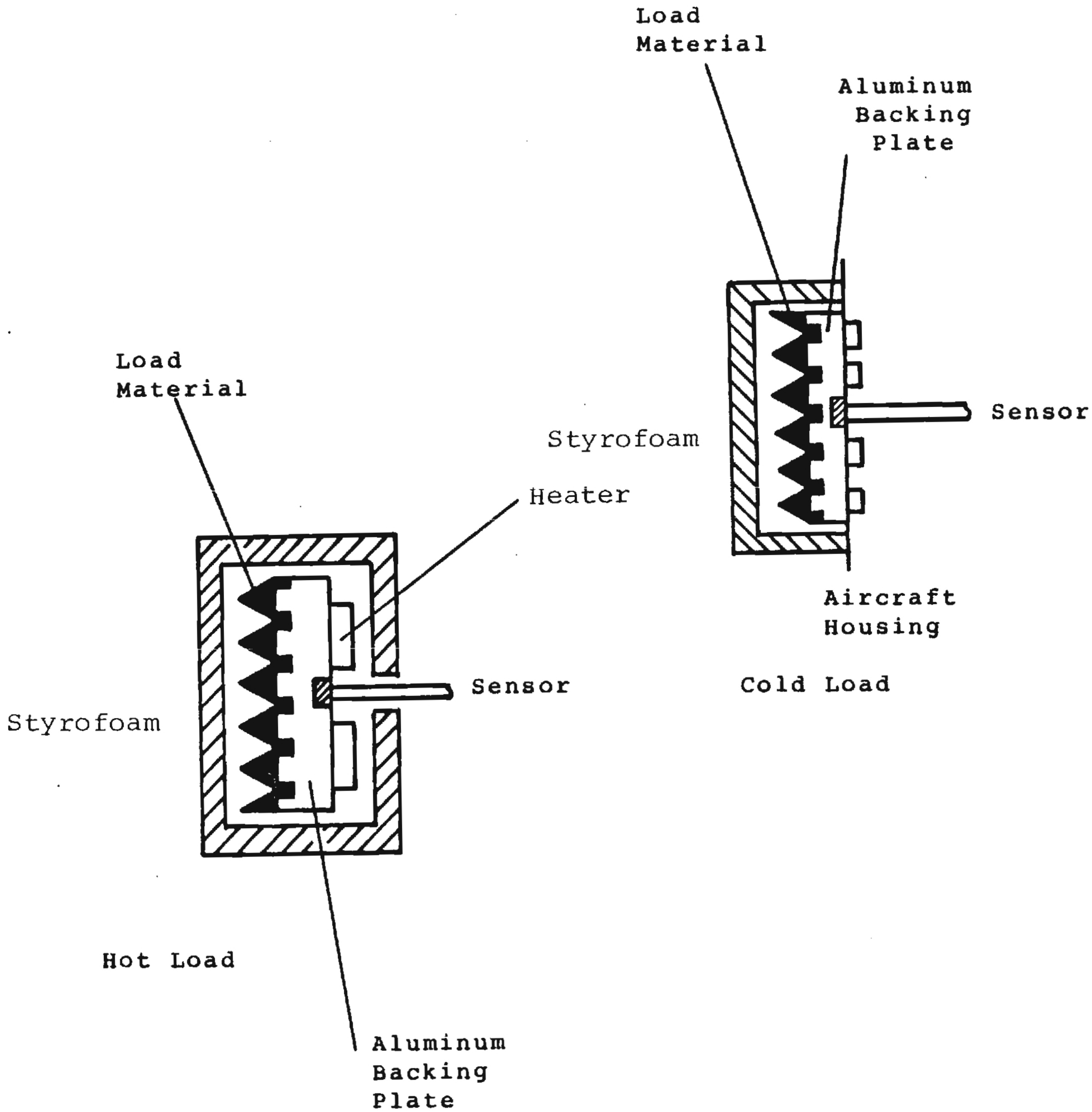


Figure 10: Calibration Load Diagram

temperature. For a 1/2 inch layer of styrofoam, the loss is approximately 0.15 dB including reflective losses. For each load, the temperature shift in the apparent radiometric temperature due to the foam loss is 0.5K maximum.

The hot load consists of a 3 inch square section of load material (described above) heated with power resistors and insulated with 1/16 inch styrofoam. A solid state temperature thermistor embedded in the aluminum backing plate, provides a reading of the average load temperature. The heater resistors are driven by a temperature controller in order to maintain the load temperature at a nominal value of 335 K.

The cold load, identical in size to the hot load, is thermally attached to the outer container which will cool the load material to temperatures about 30 to 50°C below that of the hot load. This load has a thermistor embedded in its aluminum plate for monitoring its temperature. It is sealed and insulated from the interior of the radiometer with styrofoam.

The Dicke reference load is similar to the hot and cold loads but is not directly heated. Instead, this load is thermally connected to the radiometer base plate and is warmed and controlled by the base plate heaters. A temperature monitor is not provided on this load but could be added at a later date with some minor modifications to the circuitry. However, the interior temperature of the radiometer can be measured radiometrically. During the calibration process the antenna views some absorbing material that covers one half the wheel.

2.2 Calibration Process

The calibration process takes place by steering the beam with the two reflectors as shown in Figure 11. In the automatic mode, the reflectors turn at about a one revolution per seven second rate. This is about the slowest rate of motion possible

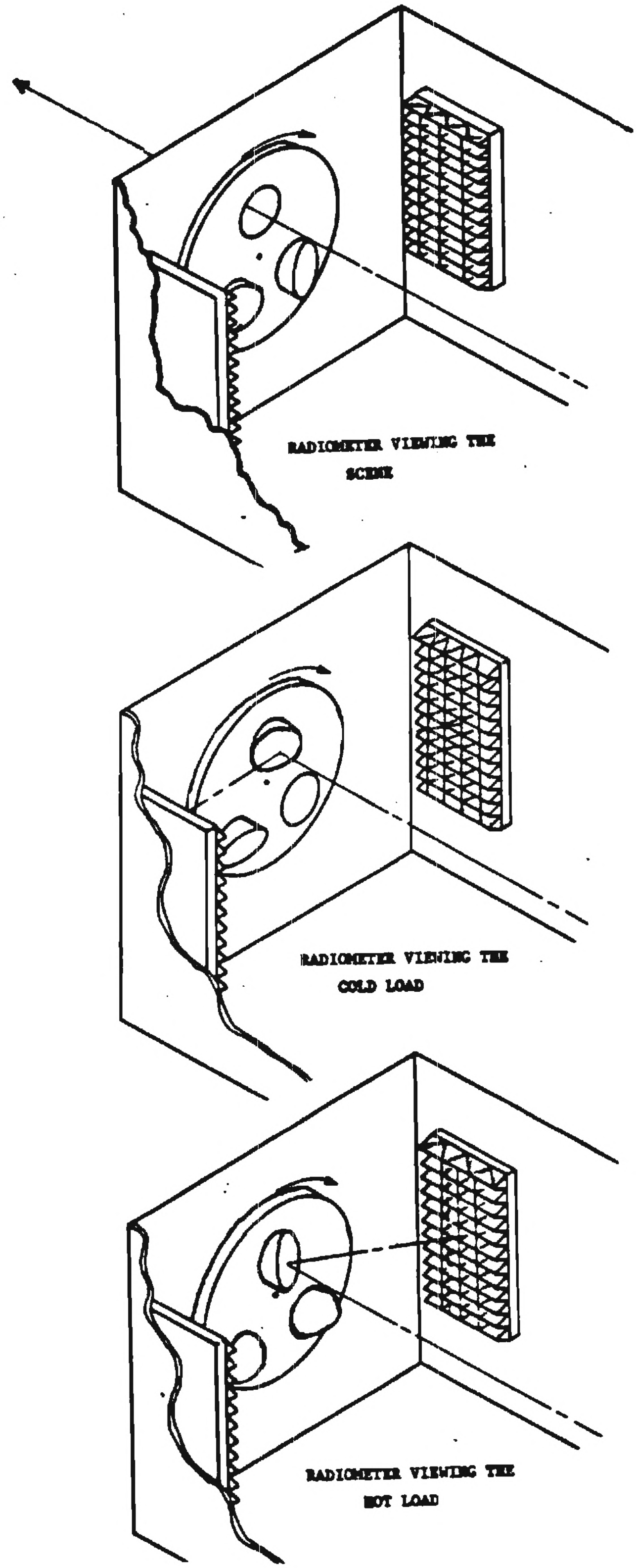


Figure 11. Calibration Beam Steering Diagram

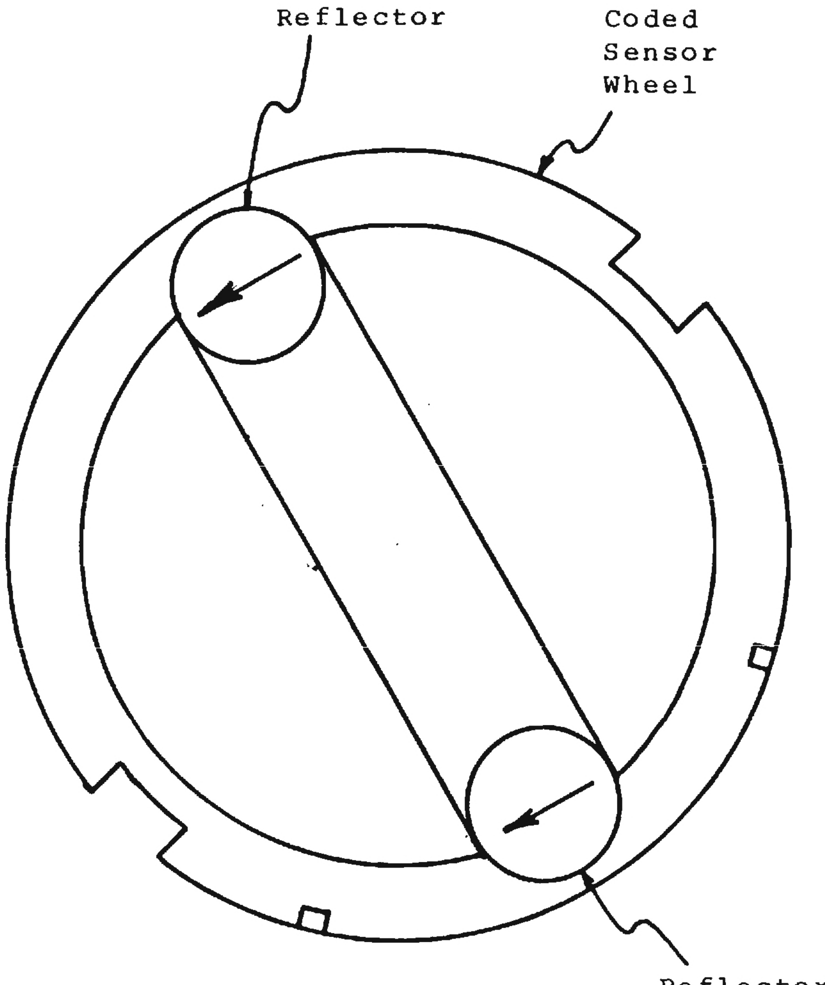
using the current motor. This motor is a geared dc motor and the slowest rate is determined by the starting torque available in the motor/gear chain combination. The position of the reflectors is sensed by the calibration sensor wheel as shown in Figure 12. The two optical sensors detect the position of the wheel which is coded by matching appropriate slots in the wheel. The sensors send out a 0 or 1 and use the code given in Figure 12 to tell the data acquisition system which of the four states the antenna is viewing (hot, cold, scene or invalid). An invalid state occurs when: (1) the reflector is only partially in the way of the antenna; (2) it is steering the beam partially away from the calibration load; or (3) it is viewing the absorber on the wheel.

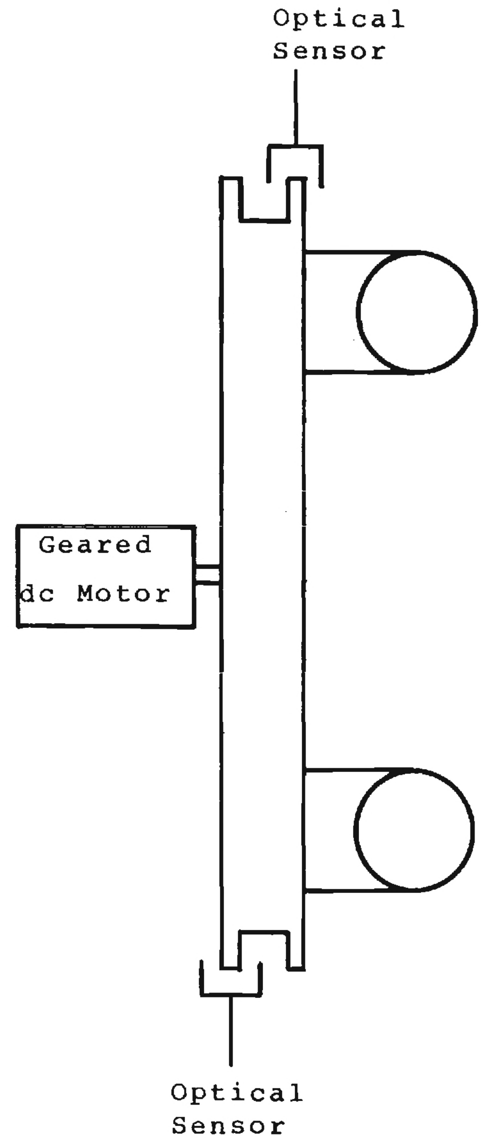
A manual calibration mode is also provided in which a SP3T switch is used to rotate the calibration reflectors to the appropriate position. Once they reach the desired state, the motor stops until ordered to move to another position by the operator. This will improve the duty cycle which is only about 20% in the automatic mode (i.e., the scene is viewed one fifth the time during a calibration cycle).

2.3 Downconverter Assembly

Table II summarizes the specifications for the dual channel downconverter assembly. A diagram of this assembly is given in Figure 13. Outputs from the preamplifiers are at about -65 dBm (for T_A = 400K) and thus require another 40 dB of gain to achieve a -25 dBm level at the input to the square law detectors. This gain is accomplished with an additional IF amplifier stage. One of the IF amplifiers failed during testing. It was bypassed and another IF amplifier was added.

The local oscillator consists of a fundamental Gunn diode oscillator and a divider to distribute power to the mixers. The Gunn device ensures that amplitude and frequency drifts due to





Calibration Code

State	Bit 0	Bit 1
Hot	0	1
Cold	1	0
Scene	0	0
Invalid	1	1

Figure 12: Calibration Wheel and Code

TABLE II

DUAL CHANNEL DOWNCONVERTER SPECIFICATIONS

RF Input	84.5 to 86.5 GHz
LO Input	85.5 GHz (Tunable $\pm$ 250 MHz)
IF Output	100 to 1000 MHz
DSB Mixer/Preamp Noise Figure	5.0 dB max at 30^{o}C
RF-IF Gain	15 dB min
Gain Variation	$\pm$1.0 dB (0 to 50^{o}C)
Dynamic Range	Noise to -20 dBm
LO-RF Isolation	20 dB min
Operating Temperature Range	0 to 50^{o}C

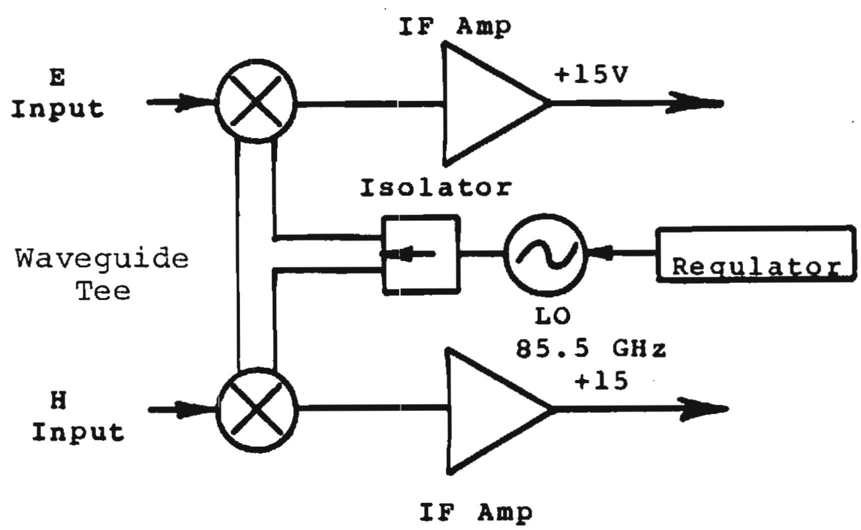


Figure 13: Mixer/Lo/Preamp Assembly Diagram

temperature change are less than 0.05 dB and 5.0 MHz respectively for a change in baseplate temperature of 1K. The local oscillator noise contributions to the overall system noise figure are minimal because the IF bands are separated from the center frequency by 100 MHz.

The baseplate is temperature controlled to minimize temperature drifts in the local oscillator frequency and system gain. Typically, amplifier gain increases by about 0.015 dB for a temperature increase of 1K. Since the baseplate is maintained at 300K $\pm$ 2.0K, the gain variations are negligible. The dynamic range of the RF/IF front end components allow the use of antenna temperatures from 0 to 600K assuming a -20 dBm maximum input at the square law detector.

2.4 IF/Video Electronics

The IF signals are amplified further after the mixer/preamp assembly by two post-IF amplifiers (one for each channel, 35 dB gain). Low pass filters are placed after the first IF preamplifier to filter out any RFI slightly above 1 GHz. The post IF amplifiers are then filtered again by another pair of low pass filters and a pair of high pass filters (fc ~100 MHz) to establish the detected IF pass band.

The IF signals are detected using square law detectors that convert the IF power to dc or video signals. These outputs are then amplified by a low noise dc coupled video amplifier to about one volt. These signals are sent along two RG188 cables to the control unit which contains the phase sensitive detector (PSD). The chopper reference voltage is sent to the control unit in the main cable so that these signals can be detected with the PSD and converted to a dc voltage. A diagram of this portion of the radiometer is shown in Figure 14. A circuit diagram for the PSD is provided in Appendix A.

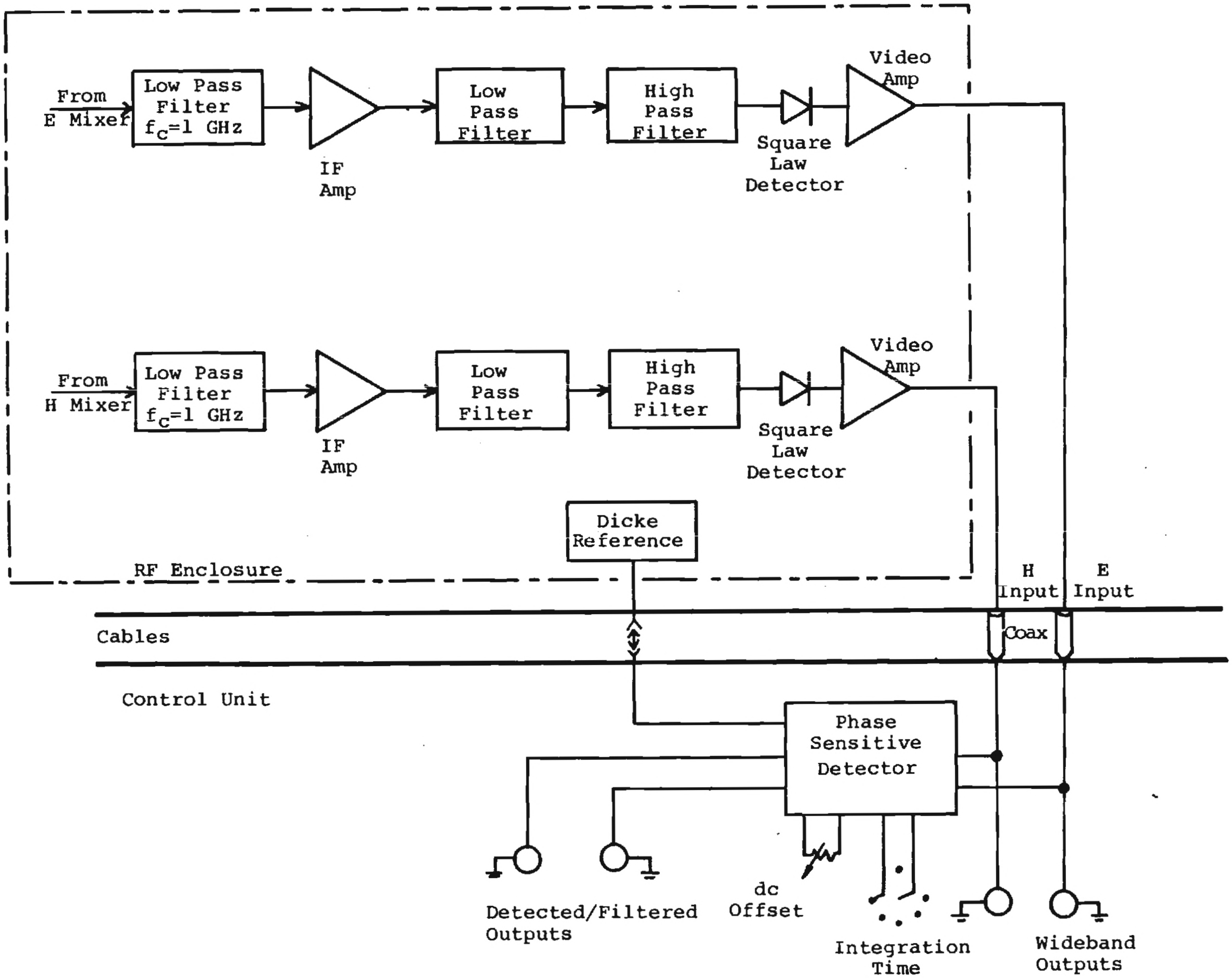


Figure 14. IF/Video Electronics

2.5 Temperature Controller

The temperature controller circuit, diagrammed in Figure 15, is located in the radiometer housing in an isolated container. It uses the aircraft (28 Vdc) supply and ground to heat the main baseplate and hot load but uses the radiometer ground and 15 Vdc to monitor the temperature of the cold load and the hot load. The Dicke load is heat sunk to the base plate to control its temperature. It is not monitored but is controlled to within a few degrees Celsius and is kept constant by the baseplate. A circuit diagram for the temperature controller is provided in Appendix A.

2.6 Motor Controller

A functional diagram of the motor controller is provided in Figure 16. The motor controller circuit is located in the same container as the temperature controller. It controls the action of the calibration motor and the Dicke chopper motor and also uses the 28 Vdc aircraft ground. The Dicke chopper motor is held constant to about 24 volts.

The calibration motor has two modes controlled by a switch located on the front panel of the control unit. The automatic mode supplies a constant voltage to the motor so that it spins at a slow rate. Its minimum speed is determined by the starting torque of the motor and the gear ratio.

The manual mode simply sends a voltage to the calibration motor until the calibration reflectors reach their desired state. The voltage then shuts off. The optical sensors tell the calibration motor controller where it is and when to stop. A circuit diagram of the motor controller is provided in Appendix A.

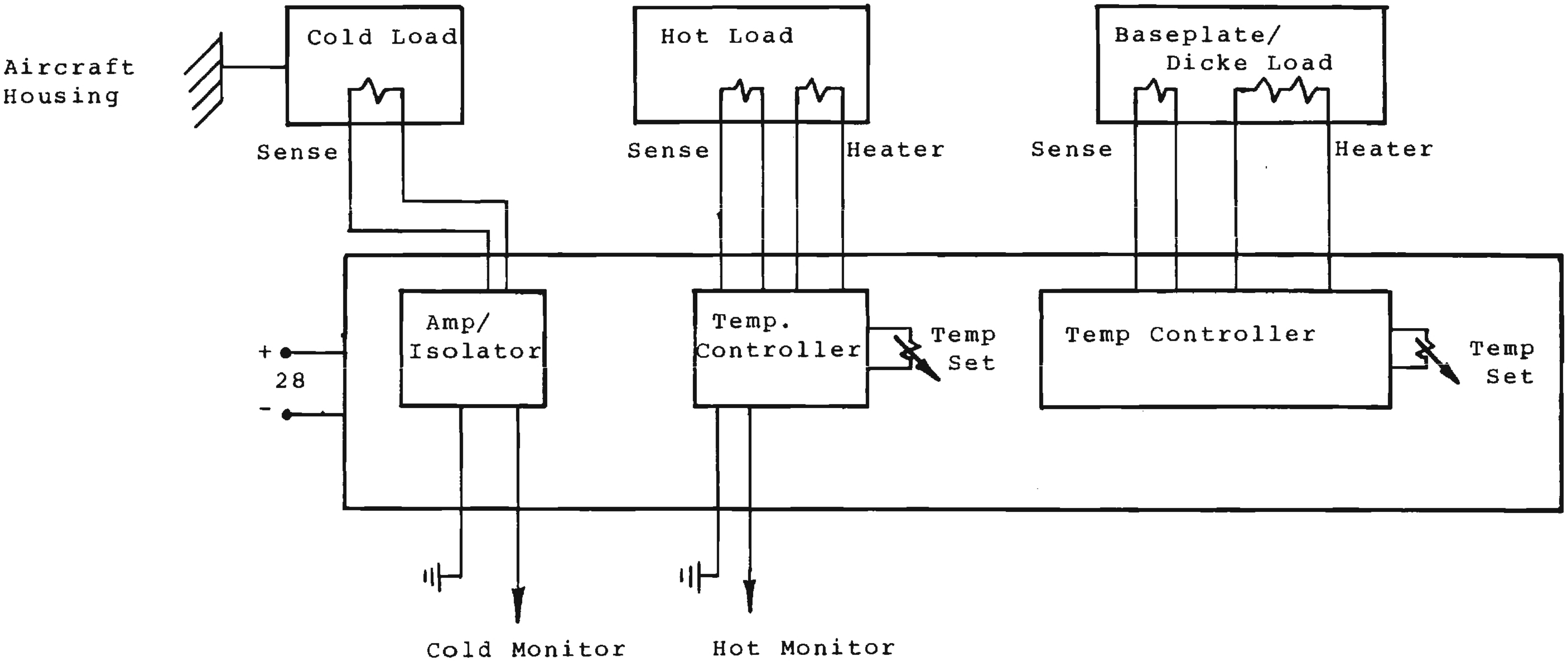


Figure 15: Temperature Controller Block Diagram

2.7 Control Unit

The control unit houses the PSD, the on/off switches, dc offset control, integration time adjustment, dc power supplies, calibration state/mode switches, Gunn current monitors and output connections for monitoring calibration load temperatures, Dicke chopper rate, radiometer outputs, and calibration state. These are summarized in Table III. Both front and back panel BNC radiometer outputs are provided for connection to the data acquisition system or lab use. In addition, a wideband output is provided which is the output of the video amplifier prior to the PSD. This can be used for total power operation if the Dicke chopper motor is disconnected and the blade secured out of the way of the beam. The integration switch or low pass filter has no effect on this output. A circuit diagram for the control unit is provided in the Appendix.

TABLE III

CONTROL UNIT MONITORS, CONTROLS AND OUTPUTS

CONTROL UNIT INDICATORS

E Voltage Analog Meter

H Voltage Analog Meter

Gunn Current Analog Meter

Calibration State LEDs (Hot, Cold, Scene)

OUTPUTS

Undetected E Voltage BNC Output (Front and Back)*

Undetected H Voltage BNC Output (Front and Back)*

Detected E Voltage BNC Output (Front and Back)

Detected H Voltage BNC Output (Front and Back)

Dicke Reference BNC Output (Back Only)

Calibration State Bit 0 BNC Output (Back Only)

Calibration State Bit 1 BNC Output (Back Only)

Hot Load Temperature BNC Output (Back Only)

Cold Load Temperature BNC Output (Back Only)

CONTROL

Main Power Switch

Gunn Power Switch

Calibration State Switch

Calibration Mode Switch

Temperature/Motor Control Power Switch

E Voltage Offset Knob

H Voltage Offset Knob

Integration Time Adjust

*Prior to phase sensitive detection

3.0 Radiometer Operation/Maintenance

This system is completely automatic with few adjustments required during normal operation. The system is operated as follows:

1. Hook-up
   a) Connect a 28 Vdc power supply to the connector in back of the control unit with all switches off.
   b) Connect the radiometer power cable between the control unit and the radiometer.
   c) Connect the BNC outputs of the radiometer to the BNC input connectors on the back of the control unit.
   d) The output can now be monitored on either of the four outputs (filtered or wideband) on the front or back of the control unit.

2. Radiometer turn-on
   a) Turn on the three switches on the left side of the control panel starting with the far left (Power, Gunn, Temp.).
   b) Allow time for the system to stabilize (about 30 minutes).

3. Radiometer turn-off
   a) Turn off the previously mentioned three switches from right to left.
4. Radiometer calibration/sensitivity
   a) Turn on the system.
   b) Set the integration time to 0.05 seconds.
   c) Alternately view calibration loads using either the manual or automatic mode and observe the respective voltages.

d) Adjust the offset voltage to be sure no electronics are saturated for temperatures expected during the data run.

e) System gain (G) in K/volt can be calculated by

$$G = \frac{T_{hot} - T_{cold}}{V_{hot} - V_{cold}}$$

Where T_{hot} and T_{cold} can be obtained by measuring the temperature monitor outputs and using Figure 17.

f) System ΔT_{min} can be measured by measuring V_{rms} using a DVM or chart recorder where V_{rms} is one-sixth the peak to peak variations. Then ΔT_{min} is given by

$$\Delta T_{min} = GV_{rms}$$

g) The T_{sys} can be calculated by using

$$T_{sys} = \Delta T_{min} \sqrt{\tau B_{IF}}$$

where B_{IF} = IF Bandwidth
and τ = integration time

5. Phase Sensitive Detector Circuit

1) The "phase" adjust potentiometer should be adjusted for a <u>maximum</u> output of the radiometer signal;

2) The adjustments for the "gain" and output "offset"

depend on the desirable system gain and offset temperature. The "offset" adjust for the PSD output is located on the front panel while the gain adjust is inside the PSD box. The gain has been preset for the anticipated temperatures and should not need readjustment.

6. Radiometer Outputs

The following outputs and voltage levels are provided on the rear panel of the control unit with isolated BN connectors:

Output	Level	
H Filtered	0-5V	dc level set by knob on front panel
E Filtered	0-5V	
H Wideband	0-5V	dc level and gain adjusted by potentiometers in the video amplifier
E Wideband	0-5V	
Hot Load Monitor	0-5V	Output voltage vs. temp. curves provided in Figure 17.
Cold Load Monitor	0-5V	
Calibration State		
Bit 0	0-5V	Calibration state as shown earlier in Figure 12.
Bit 1	0-5V	

7. Spare Parts

The following spare parts are advised:

a) Gunn diode oscillator
b) Mixer/Preamp
c) dc motor-chopper
d) dc motor-calibration

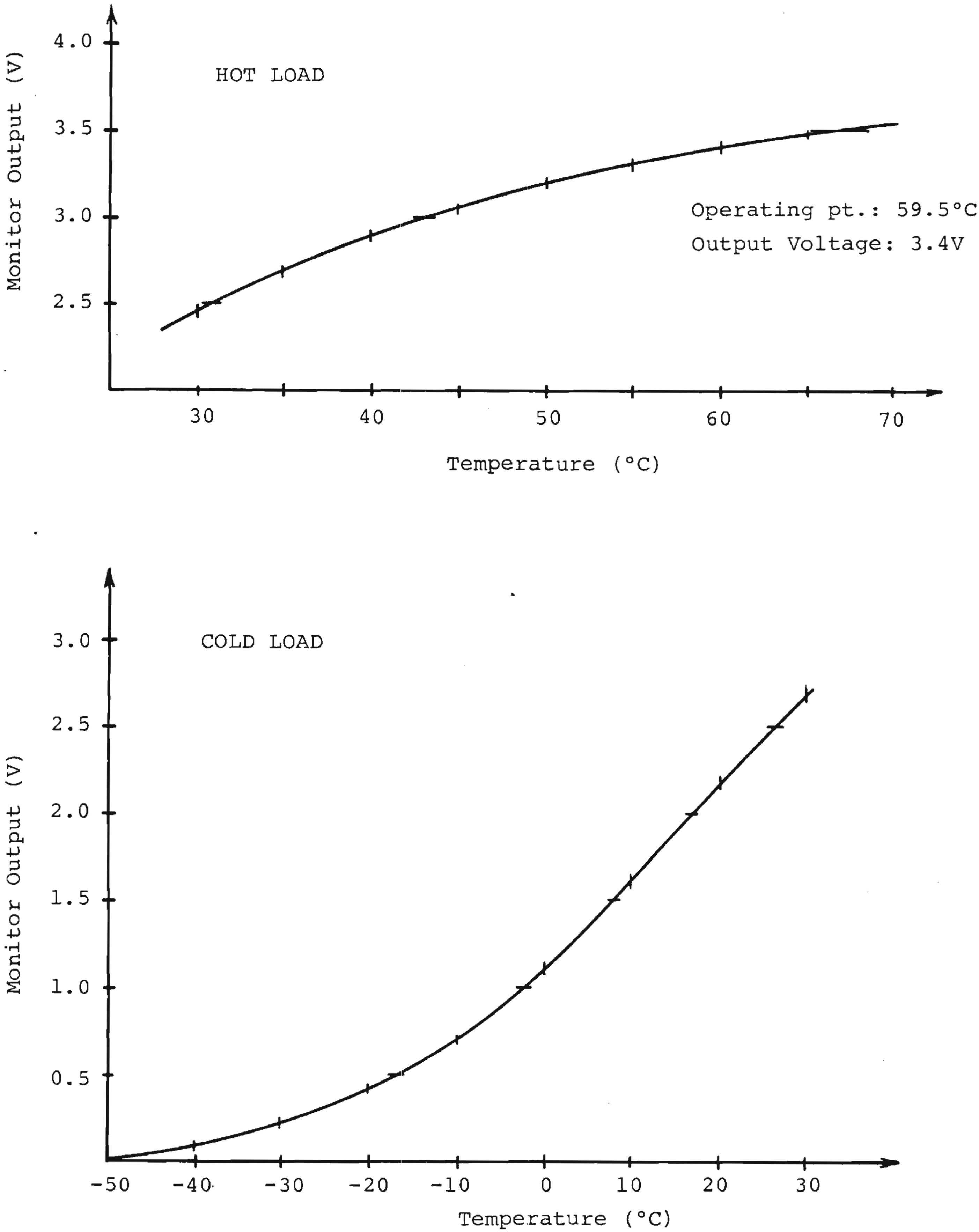


Figure 17. Monitor Output Voltages vs. Temperature.

e) Thermistor

f) Electronics (diodes, ICs etc.)

g) dc-dc converter

h) PSD boards

i) Motor controller circuit

j) Temperature controller circuit

8. Cautions

The following precautions should be taken when operating this radiometer:

a) Check that all connections are correct before applying power.

b) Automatic calibration should only be used with a 0.05 second integration time, the longer times do not settle fast enough and the shorter times allow too much ripple from the signal to pass through.

c) Keep fingers and other objects away from the chopper opening while the motor is running.

d) Check that aircraft grounds are separated from the radiometer ground.

4.0 Summary/Recommendations

An extremely sensitive, stable, 85.5 GHz dual dual channel radiometer has been designed, built, tested, and delivered to NRL for use in their RP-3A aircraft.

Remote control and output such as temperature monitors, detected and undetected, video radiometric signals and Dicke Reference signals are provided in the control unit. Control of integration time, output offset voltage, calibration motor and power are provided. The radiometer has been tested for sensitivity, noise figure, microphonics, RFI, power supply noise, and stability and has passed remarkably well.

Several further improvements are advised as follows:

1) Use ferrite switching isolators instead of the mechanical and chopper Dicke switch to increase chopping speed, and allow use of faster integration times; space has already been provided.
2) Provide a Dicke temperature monitor to allow for measurement of possible temperature change of this load; another wire on the main cable will need to be made available; the options here are: a) change the two state bits to one multilevel signal; b) use the automatic/manual signal line which would remove that feature; or c) use the 5 volt line and provide 5 volts to one motor controller from the 15V line.
3) Provide a slower motor to slow down the calibration wheel to allow more time between calibration and more samples during each look at the loads.
4) Rebuild the calibration wheel and reflectors to mount the reflectors back to back to increase the duty cycle to between 60 and 75% in the automatic mode and increase the reflectors size for more efficient coupling to the calibration loads.

Appendix

Wiring Schematics and Connector Pin Outs

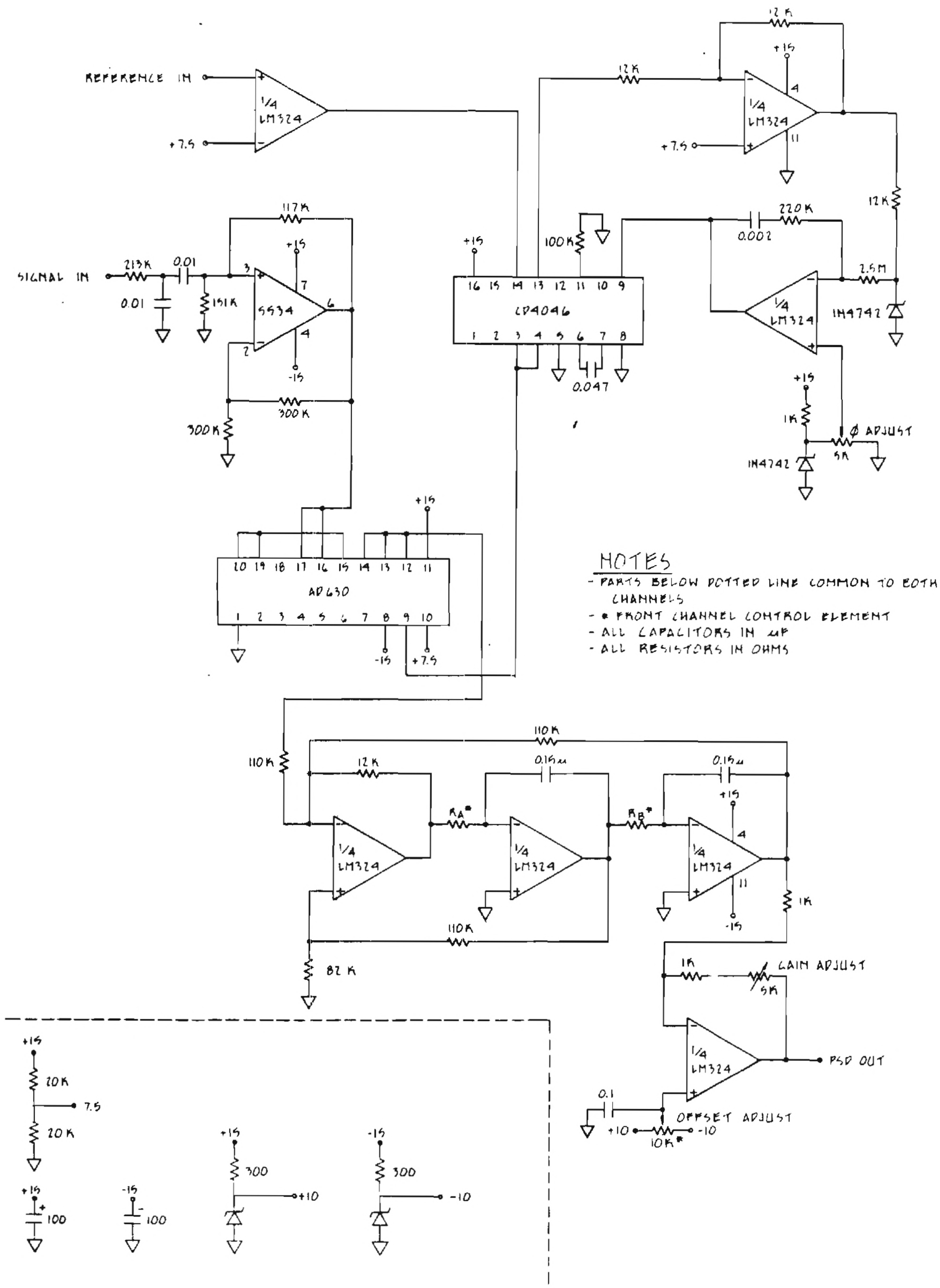


Figure A-1: PSD Schematic. Single Channel, two circuits provided, one for each polarization.

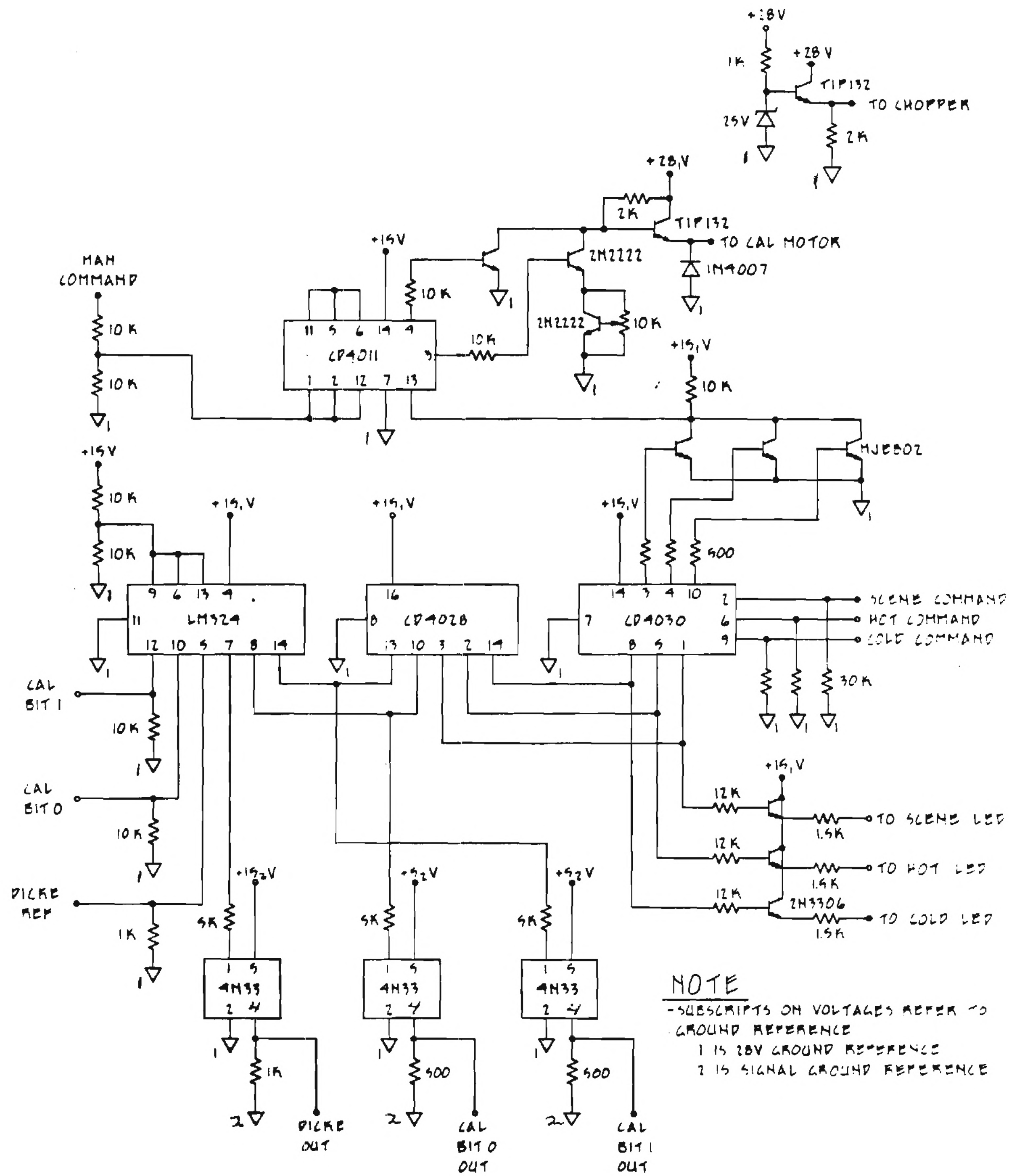


Figure A-2: Motor Controller Schematic

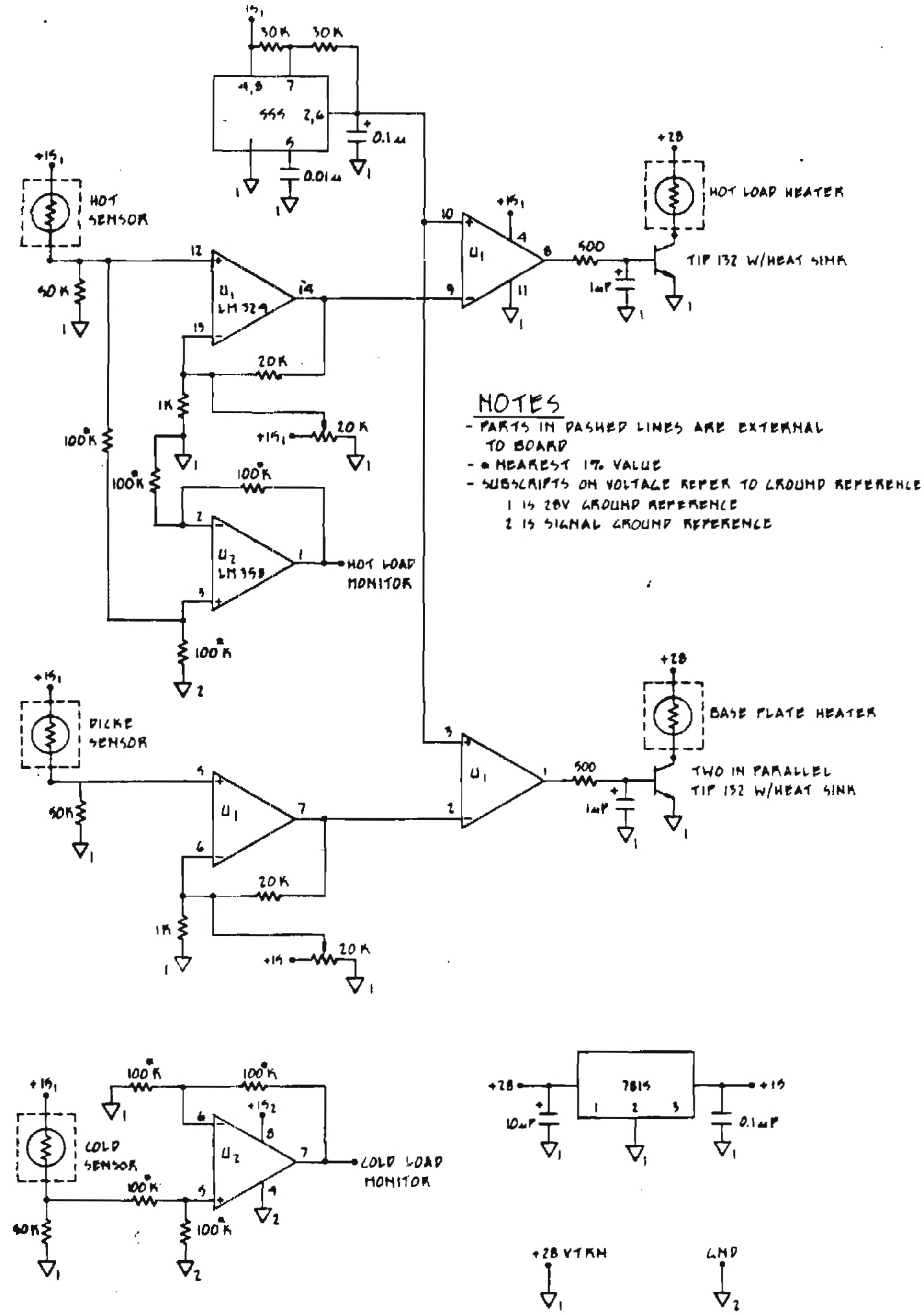


Figure A-3: Temperature Control/Monitor Schematic

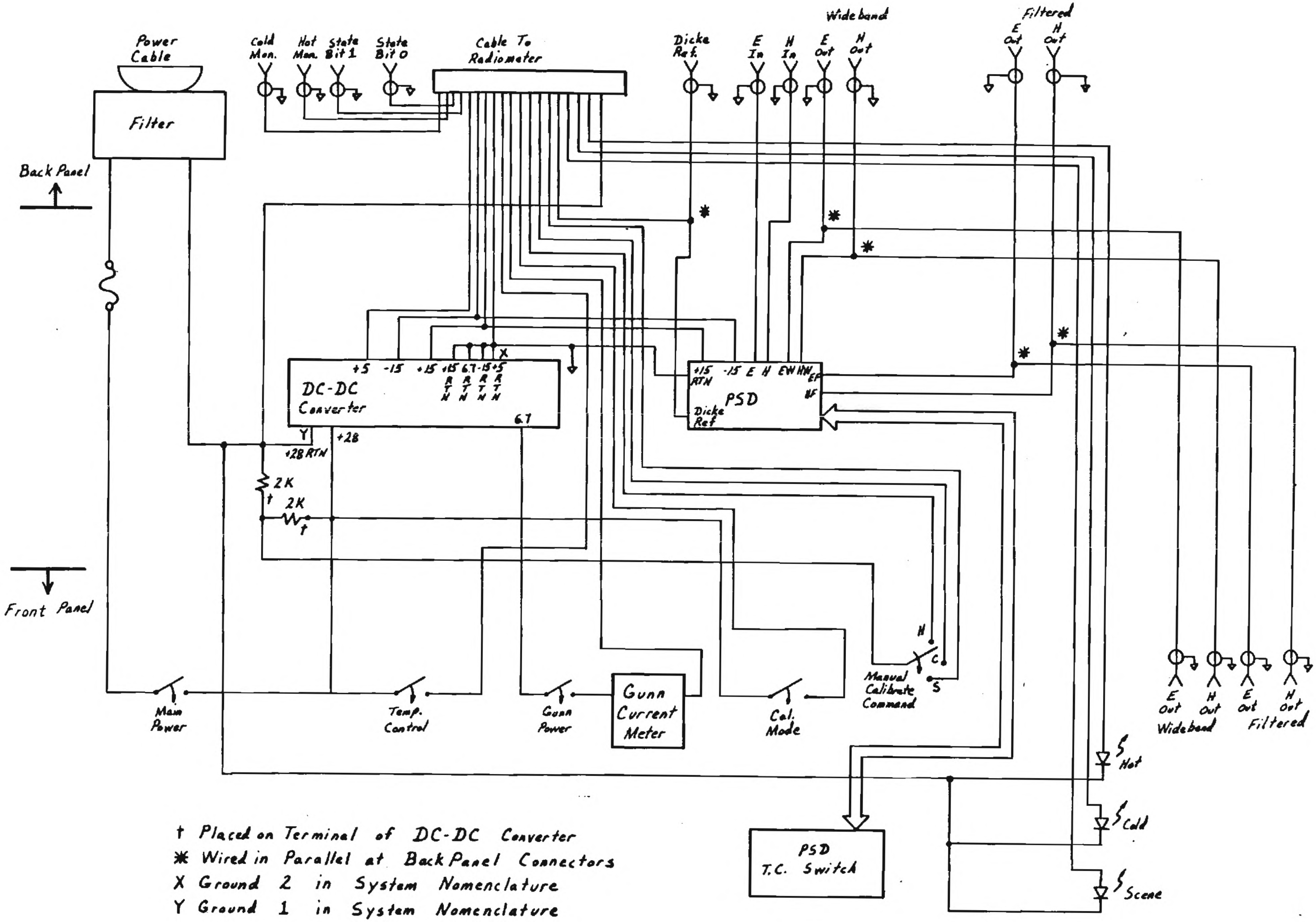


Figure A-4: Control Unit Wiring Diagram

Table A-1

RF Enclosure Connector Pin Outs

Pin No.	Assignment
1	$+15_2$V
2	-15_2V
3	$+6.7_2$V
4	GND(2)*

* GND(2) is Radiometer System ground, GND(1) is 28V Aircraft Prime Power ground. Grounds are separate and isolated.

Table A-2

Motor Controller Connector Pin Outs

Pin No.	Assignment
1	$+28_1V$
2	28_1V GND(1)
3	$+5_2V$
4	GND(2)
5	Chopper Drive
6	Cal Automatic
7	Cal Manual
8	Cold Command In
9	Hot Command In
10	Scene Command In
11	State Bit 0 In
12	State Bit 1 In
13	Chopper Sense In
14	State Bit 0 In
15	State Bit 1 In
16	Dicke Ref. Out
17	Hot LED Out
18	Cold LED Out
19	Scene LED Out
20	$+15_2V$

Table A-3

Temperature Controller Connector Pin Outs

Pin No.	Assignment
1	$+28_1$V
2	28_1V GND (1)
3	$+15_2$V
4	GND (2)
5	$+15_1$V Ref. Out*
6	$+15_1$V Ref. Out
7	Hot Sensor In
8	Cold Sensor In
9	Baseplate (Dicke) Sensor In
10	Hot Monitor Out
11	Cold Monitor Out
12	Hot Heater Out
13	Baseplate Heater Out

* Derived from 28V

Table A-4

MS 19 Pin Main Radiometer Cable Pin Outs

Pin Letter	Assignment
A	Calibration Mode
B	State Bit 0
C	State Bit 1
D	Cold Load Monitor
E	Hot Load Monitor
F	Dicke Reference
G	$+6.7_2$V
H	GND(2)
J	$+5_2$V
K	$+15_2$V
L	-15_2V
M	$+28_1$V
N	28_1V GND
P	Hot Command
R	Cold Command
S	Scene Command
T	Hot Indicator (LED)
U	Cold Indicator (LED)
V	Scene Indicator (LED)

Table A5

PSD Connector Pin Outs

Pin No.	Assignment
1	E Filtered Output
2	E Input
3	E Integration Adjust
4	E Integration Adjust
5	N/C
6	E Integration Adjust
7	E Integration Adjust
8	-15_2V
9	GND(2)
10	$+15_2$V
11	N/C
12	N/C
13	Chopper Reference Input
14	H Filtered Output
15	H Input
16	H Integration Adjust
17	H Integration Adjust
18	N/C
19	H Integration Adjust
20	H Integration Adjust
21	N/C
22	N/C
23	N/C
24	H Wideband Output
25	E Wideband Output